Indoor Air Quality: Biological organisms

DEA 350 Human Factors - Ambient Environment

Primary Biological Aerosol Particules (PBAPs)

(Jaenicke, 2005, Science, 308, 73)

- Biological materials account for 25%-40% of airborne particulates.
- Worldwide there are 10^9 tons of biological materials in the air
- Profile similar in Germany (A) and Russia (B)
- No seasonal effects

Natural Commensals

- Estimated 65 billion bacteria per square inch of upper throat (Stipp, Fortune, Jan, 20, 2003)
- High density of commensal bacteria helps to "crowd out" dangerous bacteria that could cause infection.

Ventilation and Disease

- Members of the British Parliament's House of Commons complained of a lack of "fresh air", frequent "lassitude and heaviness" and persistent epidemics of influenza.
- In 1904, Dr. Mervyn Henry Gordon was appointed to investigate.
- He gargled with an emulsion of harmless bacteria (B. prodigiosus)
- He put >200 agar plates around the chamber and delivered a 1-hour oration (reciting Shakespeare) with the ventilation system off then repeated this the next day with it on.
- He incubated the plates for 48 hours.
- The plates directly in front of him had the greatest contamination, and even the plates at the back, 62' away, showed contamination.
- The levels of contamination were higher with the ventilation system on.

Houses of Parliament Experiments

(Gordon, 1906)

Breathing Zone

- The breathing zone is the volume of a room in which occupants breathe as they stand, sit, or lie down.
- It refers to the air around a person's mouth and nose.
- Respiration creates a personal cloud in the breathing zone.

Personal Microenvironment

Personal Cloud

- The Personal Cloud concept refers to the air quality in the personal breathing zone rather than general room or ambient air.
- This is being studied using a breathing mannikin by University researchers at Syracuse and Clarkson.

Coughing

- **Coughing** - a reflex action started by stimulation of sensory nerves lining the respiratory passages. The cough reflex is a vital part of the body's defense mechanisms.
- **Inspiratory phase** – short, deep intake of breath
- **Compressive phase** - the glottis closes momentarily and bronchi constrict 50%.
- **Expiratory phase** - abdominal and chest muscles used for breathing contract, which in turn increases the pressure needed to drive air out the lungs when the larynx re-opens.

- The resulting blast of air exits the mouth at high speed (60 and 70 mph), scrubbing and clearing the airway of dust, dirt or excessive secretions.

Sneezing

- **Sneezing** (sternutation) – a reflex initiated by irritation to the mucus membranes of the nose or throat which sends a message to the sneeze center in the brain. The sneeze center sends a message to all the muscle groups that work in sequence to create a sneeze - abdominal muscles, chest muscles, diaphragm, the muscles that control your vocal cords, muscles in the back of your throat, and your eyelid muscles. It's impossible to keep your eyes open when you sneeze.
- About one of every three people sneezes when exposed to bright light; they are called photic sneezers and it is an inherited trait.
- Sneezing also occurs during plucking eyebrows.
- Fastest laboratory-tested sneeze: 103 mph.

Building Related Illnesses

- Acute Respiratory Diseases (e.g. colds).
- Legionnaire's Disease, Pontiac Fever.
- Humidifier Fever.
- Allergic disease, Hypersensitivity pneumonitis.
- Building-related illness are caused by microorganisms associated with building HVAC systems.

Sources of Microbiological Contaminants

- Ventilation system:
  - filters
  - humidifier
  - ducts
- People (viruses, bacteria, fungi).
- Plants (fungi, insects, allergens).
- Floor coverings and furnishings (bacteria, fungi, allergens).

Microorganisms in HVAC Systems

- Microorganisms can live in ventilation ducts.

Viruses

HVAC and Acute Respiratory Disease

(Brundage *et al*., 1988)

- Compared 4 army training centers over 47 month period and recorded incidence of febrile acute respiratory disease (ARD).
- 2 centers - HVAC (95% recirculated air).
- 2 centers - natural ventilation (~50% recirculated air).
- Increase risk of ARD in HVAC centers.

Office Design and Viral Illness

(Jaakkola *et al*., 1990)

- Tracked health of 893 workers (439 men, 454 women) in an 8 story office building in Helsinki over 12 months.

- Frequency of colds:
  - 14.9% none
  - 17.1% 1 cold
  - 30.0% 2 colds
  - 34.1% 3 colds
  - 3.9% >3 colds
- Results showed:
  - 35% increase in the risk of colds when workers shared offices
  - 46% increase with children
  - 107% increase with allergic rhinitis

Bacteria

- Bacteria are ubiquitous.
- Many bacteria are ~1µm.
- Ventilation duct dust can contain up to 50,000 bacteria per gram of dust.
- Dirty HVAC filters can contain up to 6,700 bacteria per gram of dust.
- Bacteria need 95% RH to survive.
- Bacteria cause many building-related illnesses.

Legionnaire's Disease

- 1976 - American Legion Conference, Philadelphia hotel.182 people ill + 29 deaths.
- > 60 outbreaks worldwide in hotels, hospitals and offices.
- *Legionella pneumophila* can thrive in cooling towers and the tower mist can be re-entrained into the HVAC system.

Legionella and Cooling Towers

- Optimal growth temperature ~35°C in water (~95°F).
- Bacterium thought to live in Amoebae in water.
- Bacterium killed in 8 minutes at 58°C (136°F).
- Bacterium killed in 4 minutes at 60°C (140°F).
- Killed by chlorination.
- Killed by UV light.

Legionnaire's Disease

- Bacterium common in soil.
- Bacterium causes Legionnaire's disease (pneumonia-like illness) or Pontiac Fever (non-pneumonia illness).
- Symptoms - malaise, headache, high fever, gastro-intestinal symptoms, respiratory failure, death.
- Legionnaire's disease mainly fatal for elderly and immune-suppressed (e.g. AIDS patients).
- > 600 deaths per year.

Legionnaire's Disease

- 1988 - BBC London.
- Contaminated cooling towers.
- 3 deaths (including HVAC maintenance person + 1 passerby).
- 96 affected by Legionnaire's disease.

Bacterial Endotoxins

- Cell walls of gram-negative bacteria contain endotoxins.
- Endotoxins are lipopolysaccharides.

- Exposure to endotoxins can cause fever and respiratory illness.
- Toxic shock syndrome is caused by endotoxins.
- Endotoxins are implicated in “sick building syndrome”

Legionnaire’s Disease

- April 1985– large outbreak at the District General Hospital in Stafford, England
- 103 cases of the disease reported
- 28 people died
- Source of the outbreak was a cooling tower.

Legionnaire’s Disease & Whirlpool Spa’s

- 1996 –23 cases (2 died) in Virginia traced to a whirlpool spa
- 1999 – outbreak at Westfriese Flora (WF) in Bovenkarspel (Province of Noord-Holland, Netherlands). The WF is a yearly exhibition of flowers, and agricultural and consumer products
  - 242 people became ill
  - *Legionella pneumophila* was isolated from two whirlpools , eleven fountains and a sprinkler .

Mesophilic Actinomycetes

- Thermophilic filamentous, colonial bacteria that thrive at 25 °C (77°F) (hence mesophilic).
- Mesophilic actinomycetes (*Streptomycetes* sp.) found in 70% of “sick buildings” vs. 10% of controls.
- *Streptomycetes* produce an intense, moldy odor.
- Mesophilic actinomycetes thrive on wet construction materials and soil.

Allergies and Asthma

- > 50 million Americans suffer from allergic
- >50% of Americans test positive to one or more allergens
- 25% of Americans allergic to either dust mite, rye, ragweed, or cockroach.
- Allergies are 6th leading cause of chronic disease in the US, costing the health care system $18 billion annually.
- >26 million Americans have asthma and ~9 million are <18 years old.
- Asthma is the most common cause of childhood hospitalizations under the age of 15.
- >5000 children die of asthma each year.
- Common triggers include fungi, pollen, pets

Fungi

Fungi

- Fungi and molds are colonial organisms (~200,000 species) that thrive on decaying matter.
- Fungal growth usually requires RH>70%.
- Fungi can grow in a wide climate range (-10°C - 65°C).
- Fungi produce toxic compounds (mycotoxins), which include the most powerful toxins known (cause liver, kidney damage, respiratory reactions). Many of these are used as antibiotics (e.g. penicillin).
- Health effects occur with inhalation/ingestion of mycotoxins, fungal spores, and fungal mycelia. At least 45 species known to cause disease (e.g

Stachybotrys chartarum, *Aspergillus flavus*).

Classification of Fungi

- Basidiomycetes - mushrooms
- Phycomycetes - molds (e.g. Rhizopus - black bread mold)
- Ascomycetes - yeast, Pencillium (some species)
- Fungi imperfecti - Pencillium (some species), Aspergillus, *Stachybotrus chartarum (atra)*, etc.

Fungi

- Fungal spores 7-12 µm diameter, but can be up to 100 µm long (shape varies with species).
- Spores can be detected in air at 30,000 feet.
- 30% of people show allergic reactions to fungal spores (wheeze cough, shortness of breath).
- Dirty ventilation ducts can contain up to 6,200 colony forming units (CFUs) per gram of dust.
- Dirty HVAC filters can contain up to 3,400 CFUs per gram of dust.

Fungi

- Health problems can be caused by spores, parts of the fungal body, and fungal metabolites (mycotoxins).

Main Genera causing Indoor problems

- Cladosporium (25 species) - brown gray/olive green colored colonies.
- Alternaria - likes warm, humid conditions, grows on textiles.
- Penicillium (200 species) - blue-green colonies, thrives in air-conditioned spaces.
- Aspergillus - likes warm, humid conditions. Thrives when heating turned on. *Aspergillus fumigatus* causes lung disease (Aspergillosis) that can be fatal.
- *Stachybotrys atra* - produces most potent mycotoxins that cause lung, kidney and liver damage.

Fungi: *Alternaria alternata*

- Grows between 2°C - 32°C.
- Optimum 25-28°C.
- Grows on wood, sick/dead plants.
- Major fungal allergen in moldy houses.
- Causes asthmatic reactions.
- Can cause skin disease.
- Produces mutagenic toxins.

Fungi: *Aspergillus fumigatus*

- Grows between 12°C - 57°C.
- Optimum 37-43°C.
- Human infective fungus, targets AIDS + immune compromised people.
- Cause of *Aspergillosis* - acts as parasite in lungs.
- Causes extrinsic allergic alveolitis (Farmer's lung) from moldy hay, wood chips etc.).

- Produces antibacterial metabolites.

Fungi: *Aspergillus niger*

- Fast growing fungus.
- Optimum 20-40°C (37°C best).
- Found in house dust.
- Causes airways allergies.
- Can cause ear infections.

Fungi: *Penicillium chrysogenum*

- Grows between 5°C - 37°C.
- Optimum 23°C.
- Found in indoor air and house dust.
- Major fungus in moldy buildings.
- First producer of penicillin.

Fungi: *Cladosporium herbarum*

- Grows even at -6°C.
- Optimum 18-28°C.
- Common in outdoor air, especially in late summer/fall and in forested areas.
- Found in dirty refrigerators, condensate reservoirs, window frames. Even grows in aircraft fuel tanks!
- Major fungal allergen causing asthmatic reactions + hayfever.

Fungi: *Stachybotris Chartarum (atra)*

- Grows from 2-40°C.
- Optimum 23-27°C.
- Only grows on wet substrate (paper, gypsum board, seeds, soil, textiles dead plants).
- Found worldwide.
- Produces several highly toxic metabolites.
- Implicated in young infant cot deaths.

Stachybotrys Chartarum

- Stachybotrys chartarum (also known as Stachybotrys atra) is a greenish-black mold.
- It can grow on material with a high cellulose and low nitrogen content, such as fiberboard, gypsum board, paper, dust, and lint. Growth occurs when there is moisture from water damage, excessive humidity, water leaks, condensation, water infiltration, or flooding.

Stachybotrys Chartarum

- In 1994, when doctors noticed that a cluster of babies in Cleveland had developed bleeding in their lungs.
- Initial research suggested that the cause might be a toxin-producing mold called Stachybotrys chartarum.
- Many of the lung-damaged babies lived in homes that had recently suffered major water damage.

Moldy Buildings
Moldy Houses

- In 1998 the pipes in the Texas mansion belonging to Melinda Ballard and Ron Allison sprang a leak.
- Massive amounts of mold bloomed, but because most of the growth was inside the walls the couple didn't realize what was going on for months.
- Their son developed asthma, tremors, and learning problems, and Allison's memory and ability to concentrate were so seriously impaired he lost his job. Ballard became convinced the problem was Stachybotrys and other molds.
- The couple sued, claiming their insurance company hadn't moved fast enough, and in 2001 a jury awarded them $32 million.
- Since then mold-related insurance claims and lawsuits have multiplied, and builders and insurers are preparing for the worst.

Moldy Houses

- Erin Brokovich bought a 5,200 ft^2 house in Agoura Hills, CA, only to find it teeming with mold.
- She, her husband and daughter have suffered a variety of respiratory ailments attributed to mold exposure.
- She's spent >$600,000 on home repairs to remediate the mold problem.
- She sued the builder (Robert Selleck, Tom Selleck's brother).

Moldy Buildings
Fungus on Floor Coverings
Damp Floors and Fungi

- Fungi can grow on and under persistently wet VCT floors.

Are all molds toxic?

- Neurospora crassa (orange bread mold)
- Although it looks harmful, studies have failed to show significant health effects of exposure.

Materials
House Dust Mite

- Microscopic arthropods - Acari (~50 µm adult).
- Two main species: *Dermatophagoides pteronyssinus* (Der p I) and *Dermatophagoides farinae* (Der f I).
- Present in most homes. Even found on planes.
- Implicated in asthma.

Dust Mite

- An ounce of house dust can contain 42,000 mites.
- Ever m^2 of material surface can contain 1,000 - 10,000 mites.
- Fabric chairs contain mites.
- A mattress contains between 1-2 million mites.
- New mattresses become infested within 2 months.
- ~15% of people are allergic to dust mites (80% to their feces, 20% to mite proteins).

House Dust Mite

- People shed ~50 million skin scales per day (~ 1 Kg per year).
- Mites feed on a fungus that feeds on the dead skin scales.
- Mites cannot feed at humidities < 70%.
- Mites take in water through their exoskeleton.
- Mites die at humidities <50%.
- Mite fecal pellets <20 μm.
- Mites are killed by UV, by dilute tannic acid, and by acaracides (benzyl benzoate).

Insects: Cockroaches

- ~ 65% of people are allergic to cockroach feces.
- Cockroach allergy is being associated with asthma.

Indoor Allergens

- Surveyed 57 children with symptoms of asthma and 54 controls from a Middle School in Los Alamos, N.M. (Platts-Mills et al., 1995)
- Among asthmatic children, sensitization to mites, cockroach, or grass pollen allergens was not significantly associated with symptoms or bronchial reactivity.
- Among asthmatic children, sensitization to cat and dog allergens was very strongly associated with bronchial reactivity and symptoms.
- Dust from houses in Los Alamos contained high levels of cat or dog allergens.

Cats

- About 56 million cats in USA.
- ~2% US population is allergic to cats
- Cat allergen (feline domesticus I - Fel d I) is a sticky glycoprotein produced by sublingual salivary glands and hair root sebaceous glands that is involved in pheromone sensing and transporting.
- Fel d I particles are ~10 times smaller than pollen or dust particles.
- Fel d I can remain airborne for months.
- Fel d I adheres to dust particles and textile fibers, including clothing.
- Fel d I can contaminate a room in 30 minutes and be detected in carpet at least 20 months after pet removal.
- In homes with cats vacuuming (regular or HEPA) increases airborne cat allergen levels ~ fourfold.
- Fel d 1 has been detected at moderate to high levels in schools, hospitals, and doctor's offices.
- Maximal risk of sensitization is between 1.7 and 23 mg/g of settled dust

Dogs

- About 65 million dogs in USA.
- Dog allergy less prevalent than cat allergy
- Major dog allergens are (Canine f 1 and 2) Can f 1 and Can f 2 - these are small-molecular-weight proteins in secretions from sebaceous glands, sublingual salivary glands, perianal glands, and epithelial cells.
- Dog allergens are lipocalins involved in sensing and transporting pheromones.

Mouse Allergen

- Airborne mouse allergen (Mus m1) detected in 48 of 57 (84%) bedrooms in inner city Baltimore houses (Matsui et al., 2005).

- Median airborne mouse allergen concentration was 0.03 ng/m^3 which is similar to levels found in animal facilities, where levels are sufficiently high to elicit symptoms in sensitized individuals.

Plants and Indoor Air Quality

(Horne, 1992)

- A majority of Architects, Interior Designers, and Facilities Managers surveyed believe that plants improve indoor air quality and worker's health in buildings.
- A majority misunderstand the research on plants and IAQ.
- A majority are unaware of potential respiratory and dermal problems with many indoor plant species (allergies).

Plants and IAQ

(Wolverton *et al.*, 1989)

- Conducted research studies on the ability of a number of foliage plant species to remove volatile organic compounds from air (formaldehyde, benzene, trichlorethylene).
- Results showed a reduction of VOC levels with plants in the experimental apparatus.

Plants and IAQ

(Wolverton *et al.*, 1989)

- Experimental apparatus:
  - Enclosed chamber
  - Single introduction of VOC contaminants
  - Potting soil with activated carbon
  - Fan to blow air through the soil
- Air samples collected immediately, at 6 hours and 24 hours.

Plants and IAQ: Breathing Wall

(Amelung., 1999)

Plants and IAQ: Breathing Wall

(Canada Life, 1997)

- Breathing wall:
  - 400 plant species
  - 50-60 animal species (fish, amphibians, insects)
- Breathing wall is claimed to be capable of removing 50-80% of some contaminants introduced to the system BUT because of multitude of variables, can't quantify the relationship between the volume of "wall" and the volume of air.

Plants and IAQ

(Larsen *et al.*, 1998)

- Compared 12m^2 (~130ft^2) offices with different plant densities (none, 10 and 22 plants).
- Ratings of comfort, attractiveness, experience and performance increased with higher plant density.
- Measured task performance decreased by 12% with higher plant density.

Plants and IAQ

(Dingle *et al.*, 2000)

- Tested effects of plants on formaldehyde levels in 5 experimental temporary 8m^2 (~86 ft^2) cabins.
- Put 5 plants every 2 days into cabins up to a maximum of 20 plants per cabin.
- Formaldehyde levels unchanged up to 10 plants per cabin.
- 12% decrease in formaldehyde with 20 plants per cabin.

- Plants are not a space efficient air cleaning system.

Sick Building Syndrome

Sick Building Syndrome

- A collection of self-reported health symptoms that are experienced when in a building:
  - irritation symptoms (mucus membrane e.g. eye, nose and throat irritation, + skin irritation)
  - neurotoxic symptoms (e.g. headache, nausea, dizziness. difficulty concentrating, hoarseness)
  - somatic symptoms (e.g. lethargy, mental fatigue)
  - unspecific hyperreactivity reactions (e.g. chest tightness, difficulty breathing, runny nose, congested nose, cough)
- Symptoms resolve upon leaving the building.

Operational Definitions

- Problem Buildings
  - Defined by objective assessment of HVAC operation and design, and/or the presence of hazardous pollutants. There may or may not be a high prevalence of SBS complaints.
- Sick Buildings
  - Defined by a high prevalence of subjectively assessed symptoms. There may or may not be an objectively measurable air quality and/or HVAC operation problem.

Laboratory studies of SBS

(Frank, 1992)

- Exposed healthy nonsmokers to clean or VOC laden air.
- Total protein and LDH in tear fluid increased with exposure to acrolein in Ss reporting eye irritation.
- 2 hours exposure to 20 $\mu g/m^3$ of 3 VOCs increased eye, nose and throat irritation, especially in "sensitive" Ss.
- Increased cognitive task errors in sensitive Ss with VOC exposure.

Climate chambers with and without office machines (Wolkoff *et al*., 1992)

Reactions to office machine emissions (Wolkoff *et al.*, 1992)

- Stainless steel climate chambers (floor area $30m^2$, 0.5 ACH, airflow 4 m/s).
- Simulated offices with and without technology.
- 30 healthy women exposed for 6 hours.
- HCHO levels 3x higher with machines running.
- O_3 fluctuated with copier activity.
- Mean TVOCs only differed during copying.
- Particulates higher with machines.
- Dry eyes, dry, stuffy nose, headache, hoarseness, breathing difficulty, dry facial skin, coughing, eye conjunctival damage and leukocyte levels significantly greater with office machines (3PCs, laser printer + photocopier).

CFD Isosurface and Temperature

(Reynolds & Hedge, 1999)

CFD Isosurface for CO^2> 675ppm

(Reynolds & Hedge, 1999)

CFD Isosurface for Temperature and CO_2

(Reynolds & Hedge, 1999)

Nonenvironmental variables affecting the number of SBS symptoms per person

(Hedge *et al*., 1994, 4,373 workers)

Parameter		Estimate	P
Intercept	Female	1.69 ± 0.38	0.0001
	Male	1.04 ± 0.39	
VDT hours		0.11 ± 0.02	0.0001
Job Stress		0.61 ± 0.06	0.0001
Job Dissatisfaction		0.42 ± 0.05	0.0001
Perceived IAQ		0.63 ± 0.02	0.0000
Age		-0.01 ± 0.00	0.0169
# Allergies		0.49 ± 0.07	0.0001
Migraine		0.63 ± 0.14	0.0001
Eyeware		0.25 ± 0.10	0.0098
Smoker		0.24 ± 0.11	0.0321

Swedish National Office Illness Project (Ericksson *et al*., 1996, 4,393 workers)

- Building factors
  - Condensation
- Personal factors
  - Gender
  - Age (weak)
  - Marital status (childless)
  - Workload stress
  - Paper index
  - Asthma, allergic rhinitis
  - VDU work (>1 hr/day)

European Audit Project (56 buildings)

(Bluyssen *et al*., 1996)

Risk indicators for SBS

- Building factors
  - Heavy traffic
  - Humidifying or cooling systems
  - Low outdoor air supply
- Personal factors
  - Gender
  - Job (stress)
  - Eczema, allergic rhinitis
  - VDU work
- Exposures
  - Low TVOCs
  - Low RH (skin symptoms)
  - Noise

Cacosmia

- Cacosmia is an “altered sense of smell, accompanied by a tendency to feel ill (e.g. nausea, headache, dizziness) from the odor of chemicals at low levels that have no effect on normals.”
  (Bell et al., Archives of Environmental Health, 47, 1993, p.316)

Cacosmia and Perceived Climate Conditions

(Hedge *et al.*, 1996)

Cacosmia and SBS

(Hedge *et al.*, 1996)

Cacosmia and SBS (PSI15)

(Hedge & Erickson, 1998)

MS6 and SBS (PSI15)

(Hedge & Erickson, 1999)

Mean Building Environment Ratings

(Hedge & Erickson, 1999)

Mean SBS ratings

(Hedge & Erickson, 1999)

Human Abilities to Detect Air Pollutants

POLLUTANTS	DIRECT SENSES
• Asbestos, fibers, particulates	None
• Radon, radiation	None
• Carbon monoxide, dioxide	None
• Viruses/ Bacteria	None
• Fungal spores	None
• Endotoxins, mycotoxins	None
• Allergens	None
• Relative humidity	None
• Sulfur/nitrogen oxides	Odor/irritation
• Ozone	Odor/irritation
• VOCs	Odor/irritation
• ETS	Vision/odor/irritation
• Temperature, air movement	Cutaneous

Psychological Influences on the SBS

- Sensation and perception.
- Attention and cognition (schema, attitudes, beliefs).
- Classical and operant conditioning.
- Arousal, stress, work demands.
- Control and coping behaviors.
- Anxiety, neuroses, aversions, phobias.
- Attribution, learned helplessness, illness behavior.
- Group dynamics, mass hysteria.
- Clinical abnormality, “hypersensitivities”.
- Management styles, labor relations, hidden agendas.
- Organizational and political climate.

Planning for Problems

- State the alternative strategies available.
- List advantages & disadvantages of each strategy.
- State costs of each option.
- Allocate responsibilities, identify 'experts'.
- Plan to deal with the media.
- Write an IEQ plan.

Written IEQ Plans

- Description of building systems with schematics for major systems and areas served.
- Daily operation and management information.
- Maintenance program, procedures, schedule.

- Visual inspection checklist.
- Archival records - as-built documents, commissioning reports, maintenance logs, training documents etc.
- Employee records - prevalence, incidence and nature of complaints, dates, remedial action,outcome.
- Clear allocation of responsibilities.